TTauri Stars in the Large Magellanic Cloud: a combined HST and VLT effort

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Abstract. The combination of the unprecedented spatial resolution attainable with WFPC2 on board HST and of the large collecting area of the VLT makes it possible to study in detail the low mass pre-Main Sequence stars in galaxies other than our own. Here we present the results of our studies of two star forming environments in our closest galactic neighbor, the Large Magellanic Cloud: the region around Supernova 1987A and the double cluster NGC 1850.

1 Stellar Populations in the Large Magellanic Cloud

When it comes to studying stars in galaxies other than our own Milky Way the Large Magellanic Cloud (LMC) is, for several reasons, an obvious starting point:

- With a distance of 52 ± 1 kpc [1] it is the closest galaxy we can look at from the outside and it is fairly easy to reach down to stars of 1 $M_\odot$, corresponding to $m_V \simeq 24$, or less.
- All of the stars are at one and the same distance.
- Our view is not severely obstructed by Galactic extinction: $E(\mathrm{B-V})_{\mathrm{Galaxy}} = 0.05$ [2].
- The stars in the LMC span a wide range of ages and physical conditions from Globular Cluster-like to star forming environments.
- Low metallicity: $Z \simeq Z_\odot/3$ corresponds to the mean metallicity of ISM at $z \simeq 1.3$ [3] at which the overall star formation rate is highest [4].

The location in the LMC of the two regions we have studied, the surroundings of SN 1987A and the double cluster NGC 1850, are shown in Fig. 1 on a Digitized Sky Survey image of the galaxy.

2 HST-WFPC2 Imaging

2.1 The Region of Supernova 1987A

The first star forming region we have considered in our search for low mass pre-Main Sequence (TTauri) stars is the one around SN 1987A. The pre-Supernova

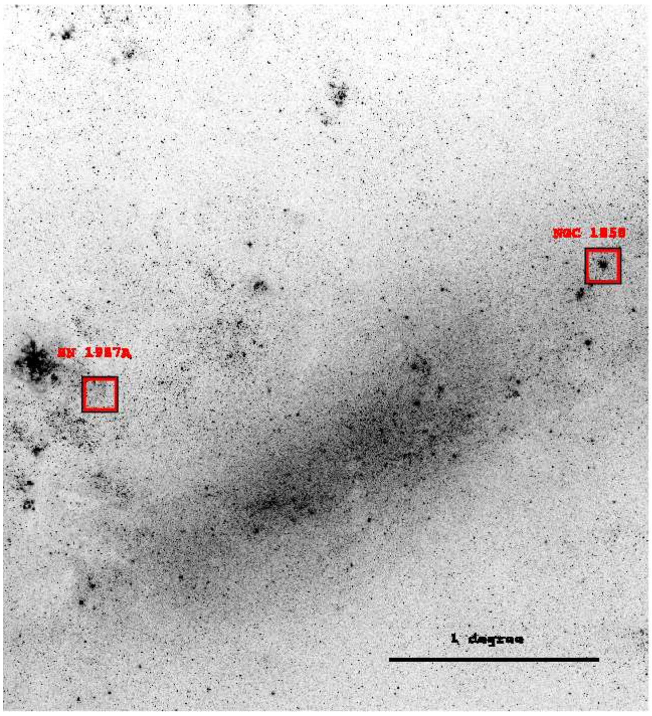

Fig. 1. The location of SN 1987A and NGC 1850 in the LMC on a DSS image of the galaxy. The scale is shown by the horizontal bar.

evolution of its progenitor, Sk -69 202 [5], is estimated to have lasted 10-12 Myr [6] and one can expect to find a similarly young population, born together with it.

From 1994 the region was imaged almost every year with the WFPC2 as a part of the long term **S**upernova **IN**tensive **S**tudy led by Bob Kirshner. This resulted in the coverage in 6 wide bands, from 2500 to 8500 Å, plus OIII 5007 Å, Hα and NII 6548 Å, of a circular region with a radius of 30 pc centered on the Supernova remnant. The HR diagram for the 21,955 stars we have identified in our multiband WFPC2 frames and for which we have derived accurate luminosities and temperatures with a new technique based on photometry alone [7] is shown in Fig. 2.

As shown in Fig. 2 there are stars of very different ages, ranging from a few million to several billions years. In particular, the location of the most massive stars in the field, except for the one highlighted in the circle, is consistent with them being coeval to the progenitor of SN 1987A which, indeed, was not born in isolation, but, rather, in a loose cluster [11]. These massive ($M \simeq 12 M_{\odot}$), bright ($\log(L/L_{\odot}) \simeq 4.5$) stars are easy to identify even in a region of complex star formation such as this one. Unfortunately, though, this is not the case for the corresponding low mass population. The expected location in the HR diagram

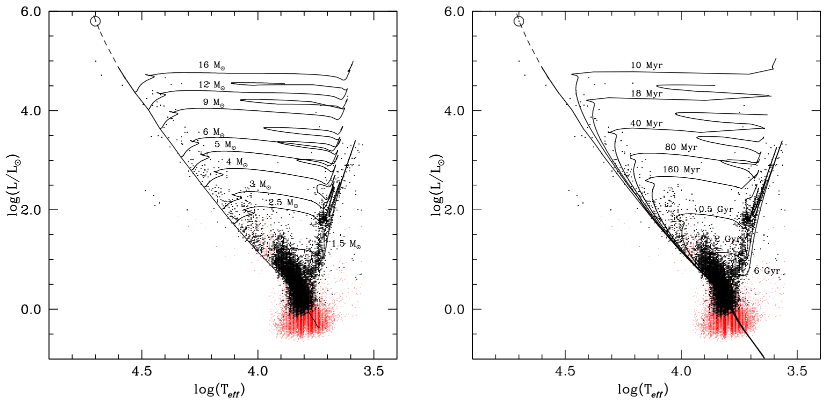

Fig. 2. HR diagram for the stars in the field of SN 1987A. Black dots are stars with $\delta\log(\mathrm{T}_{eff}) < 0.05$, while the circle highlights the most massive star in the field. Evolutionary tracks (left panel) and isochrones (right panel) by [8] and [9] are overplotted to the data. The dashed line is the upper Main Sequence as computed by [10].

for these stars ($\log(\mathrm{T}_{eff}) \simeq 3.8$, $\log(L/L_\odot) \simeq 0.2$), which are still contracting towards the Main Sequence, overlaps with the one of the (much more numerous) field sub-giants that, with a similar mass of a few solar masses, but an age of several billion years, have just left it.

The fundamental issue, which will present itself each and every time a star forming region is projected onto a much older population, then, is to find a way to identify the TTauri stars and disentangle them from the sub-giants. Luckily, the so-called Classical TTauri stars, which are thought to have a disk around them, have at least two clear, distinctive and correlated characteristics in the optical: a U-band excess when compared to a photosphere of an evolved star of the same spectral type (see, for example, [12]) and an Hα emission which can amount to several tens of Angstroms (see, for example, [13]).

Using these diagnostic tools we identified 850 TTauri candidates with U-band excess and 488 candidates with Hα emission. The vast majority of these latter ones also show an excess in the U. Let us state here very clearly that *both the criteria mentioned above will for sure underestimate the real number of TTauri stars.* On the one side, the detection level will in both cases depend on the depth of the exposures: a very shallow Hα image, for instance, will only allow to identify stars with a strong emission line. This effect is hard to quantify, as TTauri stars are variable and the features we use will vary significantly at different times. In addition, and more importantly, X-ray studies in the Milky Way [14] showed that Classical TTauri stars represent a minority of all low mass pre-Main Sequence objects. Unfortunately the so-called Weak TTauri stars do not have any clear photometric signature of their nature and they can be identified only either in the X-rays or with spectroscopy.

An example of the effects of the incompleteness in identifying TTauri stars is illustrated in Fig. 3. There the Initial Mass Function between 1 and 10 $M_\odot$ is plotted for the two recipes to identify pre-Main Sequence stars described above: Hα emission or U band excess. The derived slope is $\Gamma = -1.55$ in the first case (the classical Salpeter value is $\Gamma = -1.35$) and as steep as $\Gamma = -1.87$ in the latter one!

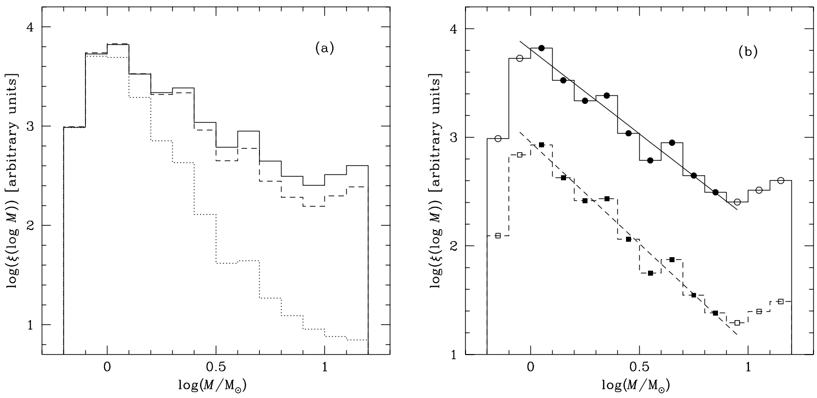

Fig. 3. Initial Mass Function in the neighborhood of SN 1987A. *Panel (a):* the IMF derived including as TTauri stars only the stars with Hα excess is shown as a full line, the one computed including also the stars with U-band excess as a dashed line. The Present Day Mass Function is also shown as a dotted line. *Panel (b):* power-law fit to the IMFs of panel (a). The bins used for the fit are marked with dots yielding a slope of $\Gamma = -1.55$ if only the stars with Hα emission are included and $\Gamma = -1.87$ if also the ones with U-band excess are considered. An arbitrary shift is applied to better show the data.

A complete discussion on the young population around SN 1987A can be found in [11].

2.2 The Double Cluster NGC 1850

NGC 1850 is a double cluster in the outskirts of the LMC bar (see Fig. 1). According to our early WFPC2 investigation [15], the main component, NGC1850A, has an age of 50 ± 10 Myr and the slope of the IMF is $\alpha = -1.4 \pm 0.2$, *i.e.* considerably flatter than the Salpeter value of -2.35. NGC1850B, on the other hand, is extremely young, 4 ± 1 Myr, and is characterized by a much steeper Initial Mass Function: $\alpha = -2.6 \pm 0.1$. In addition, there are the usual LMC field stars, as clearly indicated by the presence of the Red Clump at F439W$\simeq 20$, F439W$-$F814W$\simeq 2.2$. The color-magnitude diagram for NGC 1850 is shown in Fig. 4.

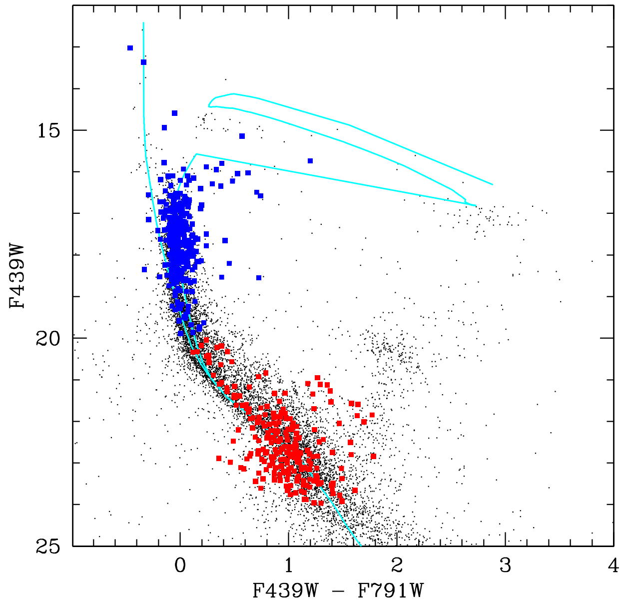

Fig. 4. F439W vs (F439W−F814W), *i.e.* roughly B vs (B-I), color-magnitude diagram of NGC 1850. The squares are Hα-emitting stars and the isochrones for 4 and 50 Myr are displayed as full lines

Once again, we know that there *must* be TTauri stars associated with the young cluster, but, as before, they are drowned in the much older sub-giant population and broad band photometry only allows for statistical arguments, but not an identification on a star to star basis. However, the addition of Hα photometry, again with WFPC2, allowed us to discover 230 Classical TTauri candidates (and 350 Be stars belonging to the older cluster). Let us stress again that the sample is by far incomplete and this number surely is a lower limit to the real content of low mass pre-Main Sequence stars. Once again, follow-up spectroscopy is needed to shed light on the low mass star population.

The full analysis of NGC 1850 will appear in [16].

3 VLT-FORS1 Spectroscopy

To recapitulate, in order to fully characterize young stellar populations projected on old field stars one has to find a way to distinguish TTauri stars from field subgiants. Both methods we have used, U-band excess and Hα emission, have allowed us to identify several hundred TTauri candidates in the two regions we have targeted. However, neither criterion yields a complete census of low mass pre-Main Sequence stars. In particular, only Classical TTauri stars can be identified, while *all* Weak TTauri stars will be missed.

Ideally, a suitably deep X-ray survey would provide a complete sample, but, unfortunately, the current generation of X-ray instruments does not have enough sensitivity to detect TTauri stars beyond the Milky Way in a reasonable integration time. In this case, then, even the Large Magellanic Cloud is too distant! Thus, in order to understand the biases introduced by the selection criteria we had to adopt on the WFPC2 imaging data, we have applied for, and were granted, two Visitor Mode nights with FORS1 on the VLT Antu (UT1) telescope in its Multi Object Spectroscopy mode. The grism we have chosen, GRIS 300V, covers a wide spectral region centered roughly at 5000 Å and including Hβ, Hα and Li I 6707 Å. The sample selected for follow-up spectroscopy consists of 20 candidate TTauri stars and as many stars that fall in the same region of the HR diagram, but without neither Hα emission nor U-band excess.

The observations were designed to fulfill two main goals. First, the spectra would provide a critical test of our selection criterion based on Hα emission and, second, they would allow to accurately determine the characteristics of our putative TTauri stars (spectral type, amount of veiling, line profile and equivalent width of the Balmer lines, etc).

Regrettably, though, we were not able to fulfill any of the proposed goals. The unfortunate combination of *El Niño* and the Bolivian winter at the beginning of the year 2000 resulted in our two nights having a seeing variable between 1.5 and $2''$: way too much for spectroscopy of $V = 21.5 - 22$ objects in a crowded field, even with an 8-meter telescope!! As a partial consolation, among other things, in those nights we did obtain several narrow band images of the region of SN 1987A and of NGC 1850, which we have used to complete our understanding of them by studying, in addition to the stars, also the interstellar medium entwined with them. As for our original goal, at the time of writing we have resubmitted the proposal to the ESO OPC for Period 68. This time, though, in Service Mode...

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